Environment. Technology. Resources, Rezekne, Latvia
Proceedings of the 10th International Scientific and Practical Conference. Volume II, 289-296

Soil erosion risk assessment at small catchments scale: comparison of GIS-based modelling and field survey data and its implication for environmental maintenance of rivers

Juris Soms
Daugavpils University, Address: Vienības Street 13, Daugavpils, LV-5401, Latvia

Abstract. **One of the limitations to implementation of effective measures to mitigate negative environmental and economic effects associated with soil erosion is the lack of data on the geographic distribution of erosion risk and potential erosion hotspots. Hence, experts and policy makers in many cases have no spatially referenced information on which to base their decisions. There is a trend approved by EU institutions and agencies to use soil erosion models which can be integrated into geographic information systems (GIS) environment in order to obtain data at different spatial scales and to assist such decision-making. Despite that, until now in Latvia only some studies on the GIS-based modelling of potential soil losses have been conducted. Considering that, in the study presented in this paper soil erosion risk assessment has been performed by the widely used Revised Universal Soil Loss Equation (RUSLE) model over five selected small catchments of the river Daugava valley. In order to validate the results of modelling and to assess if theory accords with a real situation, the theoretical data were compared with information gained from the field survey of the same catchments. Modelled potential soil loss from each of five catchments under study totals 0.25; 0.26; 0.42; 0.51 and 0.58 t ha^{-1} y^{-1} in average. However, results of the comparison indicate the discrepancies between modelled and measured values, i.e. the used empirical model underestimates the soil erosion risk. The recognition of this fact raises implication for appropriate environmental maintenance of rivers, due to possible underestimation of eroded material delivery to receiving streams and, subsequently, under-prediction of water pollution..**

Keywords: **GIS, headwater gully catchments, RUSLE model, soil erosion.**

I INTRODUCTION

The soil erosion, including the soil erosion by water, is one of the most widespread forms of soil degradation thorough the world [1]. At the same time, this process is associated with reducing of area of agricultural lands and diminishing of soil fertility, hence in many countries soil erosion is ranked among other environmental problems [2]. Moreover, soil erosion simultaneously has negative off-site impacts due to transfer of agrochemicals and eroded material from headwater catchments to receiving streams and lakes, where it intensifies processes of silting up and eutrophication [3], [4]. Thereby it is essential to carry out studies focused on these issues in order to obtain reliable data in terms of both scientific and applied aims, e.g. environmental protection and sustainable management of soils as well as water resources.

The water quality and protection of soils are some of the major concerns in the European Union member states. Considering the key objectives of the EU Water and draft Soil Framework Directives [5], [6], during the past decade attention of scientific community and policy makers has understandably focused on matters of soil erosion in respect of environmental maintenance of rivers and streams and reduction of their pollution. The rationale for such approach is obvious – the data reported by researchers suggest that the main part of sediment inputs to permanent water bodies like rivers and lakes relates to transferring of soil erosion products from adjacent landscape [7] – [9]. In order to implement effective measures to mitigate water pollution and other negative environmental and economic effects associated with soil erosion, representatives of development and planning departments of local authorities and other specialists need information on which to base their decisions. There is a trend approved by EU institutions and agencies [10], [11] to use soil erosion models which can be incorporated into geographic information systems (GIS) environment to assist such decision-making, aimed to provide sustainable management of soil resources and environmentally

ISSN 1691-5402

DOI: http://dx.doi.org/10.17770/etr2015vol2.233

wise planning of land-use. Despite that, until now in Latvia only some studies on the GIS-based modelling of potential soil losses have been conducted [12], [13]. Considering that is difficult to carry out direct measurement of soil erosion rates at large scales [14], erosion modelling is significant tool for estimation or erosion risk at local, regional and European levels.

The models developed for the purposes of assessment of soil losses caused by water erosion (for reviews, see e.g. [15] – [17]) can be divided into three groups, i.e. (1) qualitative models; (2) semi-empirical or semi-quantitative models and (3) quantitative models.

Qualitative models include those ones which are based on geomorphological approach, i.e. the direct identification and estimation of erosion features and eroded areas from satellite images or aerial photos and the preparing of thematic geomorphological maps [18], [19].

Semi-empirical or semi-quantitative models are based on simplified methods, hence allowing to employ these models on territories characterised by high complexity of physiogeographic conditions or where input data for erosion modelling is insufficient [20], [21].

According to the quantitative approach of soil erosion modelling, potential soil loss is estimated by application of empirical equations, which as input data require several numerically parameterized factors. Several quantitative models have been developed since the 70ties of the 20th century for soil loss quantification, e.g. USLE [22], RUSLE [23], ANSWERS [24], WEPP [25], EUROSEM [26], PESERA [27]. Considering the manner for describing the erosion process representation, quantitative models are classified as empirical, conceptual and physics-based [28]. Despite all these models provide information on erosion and water quality processes, they differ in terms of their mathematical complexity, input data, spatial scale and the type and the reliability of output information [16]. However, the empirical Universal Soil Loss Equation (USLE) [22], and its more recent version, Revised Universal Soil Loss Equation (RUSLE) [23], which quantifies the mean area-specific annual soil loss caused by formation of runoff on the slopes, is most frequently used worldwide at various spatial scales and different environmental contexts [29] – [31].

Considering that, the aim of the research presented in this paper was to assess soil erosion risk in the river Daugava valley by application RUSLE model and ArcGIS software.

II MATERIALS AND METHODS

The methodology followed in this research can be subdivided into three major stages: (1) input data collection, processing and computation; (2) integration of data in RUSLE model and modelling of mean soil loss by GIS tools; and (3) validation of modelling data through field assessment of soil erosion rates.

The input data for modelling were obtained from orthophoto maps, field survey, published sources of information and from high-resolution digital elevation model (DEM), which was compiled both from topographic maps and airborne laser scanning (LiDAR) data. Subsequently the results of modelling were validated through comparison of GIS-computed values and field survey data. The latter was obtained from the estimation of suspended sediment load directly during episodic runoff events in selected gully catchments.

For research purposes, five small catchments drained by gullies were chosen as model territories. Such small catchments constitute the upper part of the hydrographic network in hummocky post-glacial landscape in SE Latvia and play an important role as sources of eroded soil material. The local names of gullies which drain the corresponding catchments are Baznīcas grāvis, Pesčanij ručej, Moģiļnij ručej, Eitvinišku strauts and Ververu strauts, hence model territories were named BG, PR, MR, ES and VS respectively. All the research procedures described below were performed for each catchment.

According to Renard et al. [23] the potential soil erosion risk within the defined area, in this case – within the small catchment can be predicted by the RUSLE model, which has the following expression:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad (1)$$

where A is the mean soil loss per year (t ha^{-1}y^{-1}); R is the rainfall erosivity factor (MJ mm ha^{-1}h^{-1}y^{-1}); K is soil-erodibility factor (t h MJ^{-1} mm^{-1}); L is the slope length factor and S is the slope steepness factor (both dimensionless); C is the cover management factor (dimensionless); and P is the support practice factor (dimensionless).

Firstly, in order to perform modelling procedures, input data have been collected and the factors to be included in the RUSLE model have been computed. For this purpose literature review and survey of topographic maps and orthophoto maps was carried out, hence obtaining basic data collection.

The R factor which quantifies the effects of rainfall impact and reflects the rates of interrill erosion is not measured at meteorological stations in south-eastern Latvia. Thereby the value of this factor has been inferred from the literature [32], from the closest location where estimations of R factor is available, i.e. north-east Lithuania. Considering the close geographic location of the river Daugava valley to the mentioned region, and as result minor differences in annual amount of precipitation and its seasonal distribution, the R factor was set to value 461.2 (MJ mm ha^{-1}h^{-1}y^{-1}).

The K factor is an empirical measure of soil erodibility and depends on soil properties. For the modelling purposes K factor values were obtained in two steps: (1) deriving soil texture type from large-scale geological survey data [33] and (2) assigning values given in literature [22] for soils with corresponding texture type. In addition conformance of *K* factor values were verified with the most recent published data on the distribution of soil erodibility factor values in Europe [14].

For the obtaining of *L* and *S* values, high-resolution DEM was developed, which was compiled both from topographic maps and airborne LiDAR data. For that contour lines and spot heights were digitised from the topographic maps at scale 1:10,000 with contour interval 2 m, and subsequently ESRI Grid raster DEM was generated by ArcGIS extension Spatial Analyst tool *Topo To Raster*. In order to improve the quality and spatial resolution of DEM, raster data generated from topographic maps were combined with the LiDAR data of the same catchments by ArcGIS tool *Mosaic to New Raster*.

Considering the slope length *L* and the slope steepness *S* are topographic dimensionless factors, usually they are combined in RUSLE model and represented as integrated *LS* factor. Therefore, the *LS* factor was calculated with the previously developed DEM according to the following expressions of McCool et al. [34] used in RUSLE:

$$L = (\lambda / 22.13)^m \quad (2)$$

$$m = \beta / (1+\beta) \quad (3)$$

$$\beta = (\sin\theta) / (3 \cdot (\sin\theta)^{0.8} + 0.56) \quad (4)$$

$$S = 10.8 \cdot \sin\theta + 0.03 \text{ if slope gradient} < 9\% \quad (5)$$

$$S = 16.8 \cdot \sin\theta - 0.5 \text{ if slope gradient} > 9\% \quad (6)$$

where λ is the length of the slope; m is a variable length-slope exponent; β is a factor that varies with slope gradient, and θ slope inclination angle.

For further modelling purposes, *S* factor was derived from DEM by raster processing tool *Slope*, and *L* factor was derived by combination of two raster processing tools – *Flow Direction* and *Flow Length*. Then formulas (2); (3); (4); (5) and (6) were used to obtain the *LS* factor values.

The *C* factor values were obtained from identification of land cover types on the basis of analysis of orthophoto maps. In addition, field survey of this factor was performed, allowing to distinguish the following land cover classes in the catchments under study: grassland and rangeland, arable land, garden, orchard, forest, scrub and pond. Then *C* factor was parameterised by assigning a uniform value given in the literature [22] to each land cover class.

Finally, the support practice *P* factor (dimensionless) was set to value '1' because there are no specific erosion control practices in the studied catchments, hence this factor has no impact on the resulting soil losses.

Because RUSLE model deals with input data which have geographic reference to their location, i.e. these data are geospatial data, the availability of GIS instruments facilitated the automatization of calculation procedures. Therefore the mean annual soil loss for the each of five catchments were calculated for a 1 × 1 m cell grid by ArcGIS tool *Raster Calculator* according to the following SQL codes developed by Grišanovs [35] for application in GIS:

```
L=Pow(([FlowLength]/22.13),(((Sin([Slope]·3.14159/180)/0.0896)/(3·Pow(Sin([Slope]·3.14159/180),0.8)+0.56))/((Sin([Slope]·3.14159/180)/0.0896)/(3·Pow(Sin([Slope]·3.14159/180),0.8)+0.56)+1)))

S=(10.8·Sin([Slope]·3.14159/180)+0.03)+(16.8·Sin([Slope]·3.14159/180)-0.5)

A=461.2·[K]·[L]·[S]·[C]
```

This procedure allowed to obtain data at high spatial resolution because potential mean annual soil loss values were calculated for each cell of 1 × 1 m regular grid.

The results of modelling were compared with the data on sediment load from gully catchments carried by temporary streams. To do that, first of all, measurements of discharge Q (m^3 s^{-1}) and sediment concentration C_S (mg l^{-1}) were carried out during the formation of runoff in gullies which drain corresponding catchments. Than sediment load Q_S (kg s^{-1}) was estimated applying the relationship (7) given in the literature [36]:

$$Q_{SS} = Q \cdot C_S \quad (7)$$

After that, in order to get comparable values of suspended sediment load from gully catchments that differ in size, an area-specific daily sediment yield SY_D (kg ha^{-1} day^{-1}) was derived by formula (8). Namely, the area-specific daily sediment yield SY_D can be expressed as the established ratio between the corresponding sediment load Q_S (kg s^{-1}) multiplied by the time span equal to one day expressed in seconds and the contributing area of catchment C_A (ha), hence SY_D can be calculated from:

$$SY_D = Q_S \cdot 86400 / C_A \quad (8)$$

Finally, the reasons why the modelled and measured assessments of erosion rates differ are discussed hereinafter in the paper.

III RESULTS AND DISCUSSION

A. Characteristics of catchments

Considering their topography, all five catchments have a similar structure, i.e. the drainage area could be subdivided into two parts. The (1) upper part or gully channel contributing surface are represented by morainic slightly undulated plain with rather gentle slopes, whilst the (2) lower part are represented by river valley slope dissected by gully and with steeper slope gradient. This can be distinguished in a digital elevation model of catchment BG in Fig. 1. Typically the upper parts of catchments stretch at elevations above 140 m a.s.l., but their lower parts are located at elevations from 90 to 92 m a.s.l. Thus, high vertical difference between contributing areas and local base level creates favourable conditions for soil erosion process.

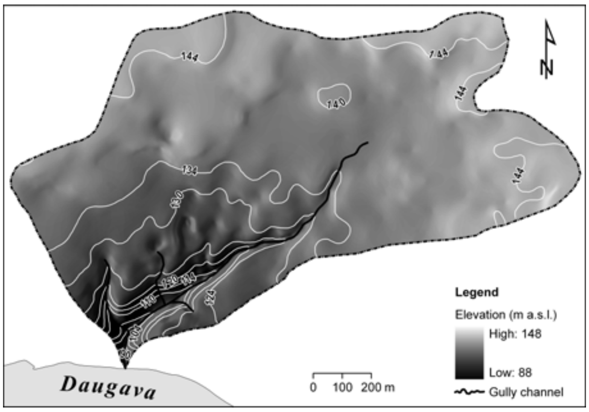

Fig. 1. Topography typical for gully catchments under study: an example of BG catchment, showing relief by a shaded DEM in the background.

Considering a lithological diversity of Quaternary deposits combined with intricate topography, a variety of soils can be identified within model territories. However, Stagnic Albeluvisols, Albic Rubic Arenosols and Albic Stagnic Podzols are dominant types of soils. Despite the variety of soils, the selected gully catchments have similar properties in respect of erodibility because glacial till derived stony loamy – clayey diamicton sand textures prevail in the selected catchments. Hence, values of erodibility *K* factor of the top-layer are more or less similar.

Comparison of the gully catchments under study which is given in Table I indicates, that the most significant differences can be distinguished concerning morphological features, i.e. catchments area and gully network drainage density, as well as vegetation and land cover.

These factors namely determine the difference in a formation and rate of runoff and, thus, control the soil erosion. That reflects the notable variation in the susceptibility of small catchments to mobilization and transferring of soil erosion products due to spatial alteration of controlling factors.

Theoretically, considering the morphology of gully catchments, particularly the mean slope of gully channel contributing surface (Table I) which is one of the main erosion controlling geomorphological factors [37], the ES and VS catchments are the most prone to soil erosion, and hence should present the highest values of soil losses. Both aforementioned catchments also are characterised by comparatively high drainage density (3.71 km km^{-2} and 3.45 km km^{-2} respectively) and as a result more rapid draining of water and subsequently, higher transporting capacity of eroded sediments and their transferring it to the receiving stream.

TABLE I

MAIN MORPHOLOGICAL CHARACTERISTICS OF GULLY CATCHMENTS UNDER STUDY

Characteristic	Catchment				
	BG	PR	MR	ES	VS
C_A (ha)	139.06	74.67	124.44	68.93	59.06
WLR	0.59	0.28	0.48	0.65	0.39
LB (m)	58	72	56	87	84
DD (km km^{-2})	1.16	1.72	0.88	3.71	3.45
S_m (m m^{-1})	0.029	0.034	0.025	0.058	0.064
GL (m)	1230	1160	860	1010	860
GG_m (m m^{-1})	0.043	0.044	0.040	0.063	0.056
PVC (%)	11.10	9.64	81.20	44.35	42.95

Note: C_A = catchment area; *WLR* = width-length ratio of catchment; *LB* = local base level equal to max. difference in local topography within catchment; *DD* = drainage density of gully network (including side branches) within catchment; S_m= mean slope of gully channel contributing surface; *GL* = gully length; GG_m = gully thalweg mean gradient; *PVC* = proportion of area under protective canopy vegetation cover (forest and scrub) within catchment.

Review of literature indicates [38] that besides the geomorphological factors, the protective canopy vegetation cover and land use also are significant factors affecting soil erosion rates. Therefore, the spatial analysis of land cover patterns and calculation of a specific area for each landscape mosaic element was carried out. In Fig. 2, the calculated ratio among different land cover classes for each of the studied gully catchments, obtained from aerial photographs by GIS analysis, are shown.

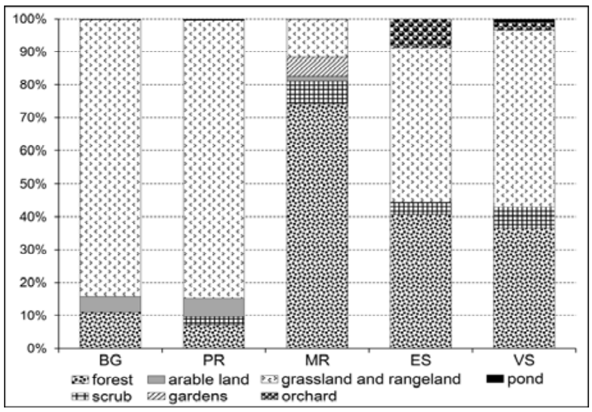

Fig. 2. Land cover classes and their proportion in each gully catchment under study.

The arable land in the territory under study constitutes less than 5% of the total gully catchments BG, PR and MR area (e.g. 4.74%, 5.67% and 1.41% respectively), while in catchments ES and VS this type of land cover is not presented at all. At the same time, forest canopy vegetation covers more than 40% of the area of three of these catchments, i.e. MR, ES and VS. Hence, it can be anticipated less erosion rates and associated eroded material delivery from these model territories.

B. Results of RUSLE modelling

The potential mean annual soil loss A under present land use in the gully catchments BG, PR, MR, ES and VS modelled by RUSLE was 0.51; 0.58; 0.26; 0.25 and 0.42 t ha^{-1}y^{-1} respectively (Table II). Within catchments the modelled values of soil loss are characterised by high deviation and variation – statistics indicates that these indices can reach values up to 527%. Such a high dispersion can be explained by high spatial variability and physical entity of input data used in RUSLE model – these data represent independent phenomena or values, which are non-correlated each other.

TABLE II

RESULTS OF MODELLING OF ANNUAL SOIL LOSSES FROM GULLY CATCHMENTS

Catch-ment	N	Potential mean annual soil loss (t ha^{-1}y^{-1})			$STDV$ σ	V (%)
		A_{min}	A_{max}	A_{avg}		
BG	1 390,581	0.0	62.91	0.51	1.558	305
PR	746,747	0.0	150.62	0.58	2.165	373
MR	1 244,375	0.0	62.83	0.26	1.369	527
ES	689,346	0.0	8.99	0.25	0.376	150
VS	590,590	0.0	8.93	0.42	0.598	142

Note: N = number of grid cells used for calculations of statistics; A_{min} = minimal modelled potential mean annual soil loss at catchment; A_{max} = maximal modelled potential mean annual soil loss at catchment; A_{avg} = average modelled potential mean annual soil loss at catchment; $STDV$ = standard deviation of the modelled A values; V = variation index.

However, at the catchment scale average A values varies greatly depending on land cover type, corresponding to 5.59 t ha^{-1}y^{-1} for cropland and arable land, 0.27 t ha^{-1}y^{-1} for grassland and rangeland, and 0.12 t ha^{-1}y^{-1} for forestland. The average soil loss modelled rates of cropland was about 20.7 times that of grassland, and 46.5 times that of forested land. The spatial distribution of the soil erosion risk is uneven and differs both among the catchments and at the each catchment.

The spatial distribution of the erosion risk represented by potential soil loss, as shown on example of BG catchment in Fig. 3, was divided into five categories: Category 1, very low risk (potential soil loss 0 – 0.3 t ha^{-1}y^{-1}); Category 2, low erosion risk (potential soil loss 0.3 – 1.0 t ha^{-1}y^{-1}); Category 3, moderate erosion risk (potential soil loss 1.0 – 3.0 t ha^{-1}y^{-1}); Category 4, high erosion risk (potential soil loss 3.0 – 10 t ha^{-1}y^{-1}); and Category 5, very high erosion (potential soil loss >10 t ha^{-1}y^{-1}).

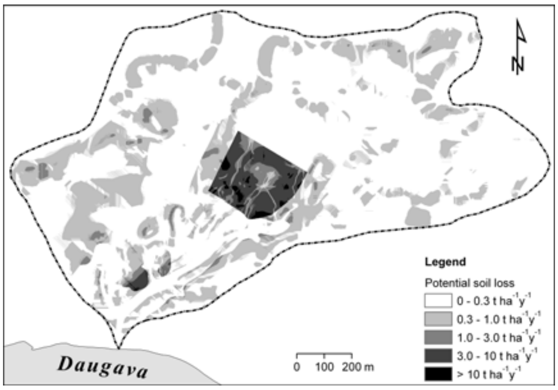

Fig. 3. Spatial distribution of modelled soil erosion risk represented by potential soil loss (t ha^{-1}y^{-1}): an example of BG catchment.

The regularity elucidated during analysis of data indicates that the lowest soil erosion risk Category 1 included mostly forested areas, whilst the higher soil erosion risk categories, i.e. Category 4 and Category 5 geographically coincide with arable land.

The data obtained on potential soil loss indicate, that despite the ES and VS catchments are characterized by the highest mean values of contributing surface slope and theoretically both catchments are most prone to soil erosion, the modelled A values are comparatively small, contrary to anticipated results. This fact can be explained by the highest proportion of area under the protective canopy vegetation cover within both these catchments.

C. Results of field assessment of soil erosion rates

Area-specific daily sediment yield SY_D (kg ha^{-1} day^{-1}) as eroded material output from catchments was calculated for short measuring periods, using the methods described in the section "Materials and methods". Calculation of the mean annual load was not performed because such an approach is incorrect if the measurements of input data have been carried out *in situ* only during runoff causative weather events. The obtained results on SY_D are summarized in Fig. 4.

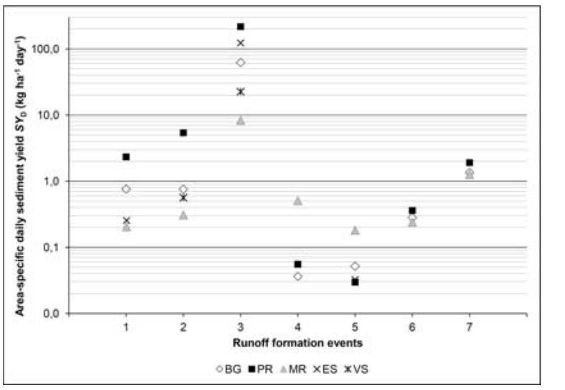

Fig. 4. Comparison of area-specific daily sediment yield SY_D of catchments under study for different runoff events

The highest area-specific daily sediment yield SY_D occur for the PR catchment, which is possibly associated with the lowest percentage of canopy vegetation cover and the highest percentage of agricultural land.

For the reasons of comparison, the modelled potential soil loss A values were downscaled at temporal scale to obtain it daily values, which, in fact, correspond to SY_D. Comparison of modelled versus measured values indicates that the applied RUSLE model underestimates real sediment delivery, which shortly can reach values 217.63 kg ha^{-1} day^{-1} during intense snow melting in spring. Hence, in fact, the 'theory' does not reflect 'reality'. This discrepancy why the two assessments of erosion obtained from GIS-based modelling and field survey data differ can be associated with several reasons. First of all, RUSLE model doesn't take into consideration possible influence of high-intensity hydro-meteorological extremes as well as the impact of rill and gully erosion on sediment production from catchments. Consequently, these errors are not included in calculations of mean values, leading to inadequate evaluation of erosion risk. This fact is also indicated in the literature [40]. Secondly, the field observations indicate that the most of the eroded material is supplied from the erosion of cohesive gully sidewalls and rewashing of material replaced downslope into gully channels by mass movement processes; less the eroded material is supplied from the surface erosion in the catchment area by such processes as overland flow. This demonstrates that gullies certainly contribute to the sediment yield from a catchment even if a process of downcutting does not occur. This also indicates that suspended sediment comes from two different sources, i.e. soil erosion of the catchment surface, and lateral erosion of the channel banks, when fine material is thrown into suspension by the temporary stream after a bank collapse, however, quantifying this effect is difficult. Finally, the presence of boulders and very coarse material in glacial till-derived soil, which is not taken into consideration in calculations of K factor values, enhances turbulence of the stream and, consequently, the associated erosivity.

Summarizing the results obtained in this research, as well as above discussed issues, it is possible to conclude that the applied modelling underestimates real values of sediment delivery from headwater catchments, hence causing implications for development of appropriate erosion risk reduction practices and adequate measures to maintain environmental quality of the river. Nevertheless, results of GIS modelling can be reasonably used to estimate the spatial distribution of soil erosion risk and to identify potential erosion hotspots.

IV CONCLUSIONS

The application of RUSLE model, originally developed for application in the farming sector at local scale, if applied to a catchment scale in different landscapes and various environmental and climate conditions, must take into account some limitations. The obtained values of potential soil loss and corresponding erosion risk must be employed adequately, only for indicative or comparative purposes, and not considered in absolute terms.

The analysis of data carried out in this study has showed that the current approach of RUSLE erosion model underestimates the proportion of the sediment load which is transferred from erosion sources associated with contributing surfaces of headwater catchments.

Field observations indicate that important factors affecting sediment mobilization and delivery to receiving rivers are erosion and mass movement processes within gully channels. Hence, a major limitation for the soil erosion risk assessment by RUSLE is that accelerated erosion by streams, mass movements and gully sidewalls erosion most often are not considered in calculations. In addition eroded material output is very responsive to extreme runoff events, leading to a strong underestimation of loads when using empirical models like RUSLE based on the mean values of factors.

Although the results of RUSLE modelling, in general, can be used as a basis for management and environmental maintenance of rivers, until better models will be implemented and adapted, policy makers and decision taking institutions should treat the results of soil erosion risk assessment with some caution.

The GIS-based RUSLE modelling enables scientists, experts of local authorities and other specialists to identify erosion risk areas and potential erosion hotspots and to implement mitigation and control measures with a respect of limiting environmental damages and related costs. According to Glymph [41], 'It costs less to keep soil on the land than dredge it from waterbodies', hence the approach 'control at source to prevent water pollution by sediment' should be implemented wider by local authorities and responsible experts for environmental maintenance of rivers, in particular given the situation of limited resources for developing and implementing erosion mitigation measures.

ACKNOWLEDGMENTS

Research reported in this paper was financially supported by the ESF project No. 2013/0020/1DP/1.1.1.2.0./13/APIA/VIAA/066 „Interdisciplinary Team of Young Scientists for Assessment and Restoration of Soil Quality and Usage Potential in Latvia".

REFERENCES

[1] E.M. Bridges and L.R. Oldeman, "Global assessment of human-induced soil degradation," Arid Soil Res. Rehabil., vol. 13(4), pp. 319–25, Nov. 1999.

[2] C. Valentin, J. Poesen, Y. Li, "Gully erosion: impacts, factors and control," CATENA, vol. 63 (2-3), pp. 132–153, Oct. 2005.

[3] J. Poesen, J. Nachtergale, G. Vertstraeten, C.Valentin, "Gully erosion and environmental change: importance and research needs," Catena, vol. 50 (2–4), pp. 91-133. Jan. 2003.

[4] B.Wu, G.Wang, J. Xia, X. Fu, Y. Zhang, "Response of bankfull discharge to discharge and sediment load in the Lower Yellow River," Geomorphology, vol. 100 (3-4), pp. 366-376. Aug. 2008.

[5] European Commission, "Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (The Water Framework Directive 2000/60/EC)," OJ L327, pp. 1–73, 2000.

[6] European Commission, "Thematic Strategy for Soil Protection [SEC(2006)620][SEC(2006)1165]," COM (2006) 231 final. Brussels, Commission of the European Communities, 12 pp., 2006.

[7] S. Anthony, "Cost and effectiveness of policy instruments for reducing diffuse agricultural Pollution", Report for DEFRA projects WQ0161 and ES0205, 119 pp., 2006.

[8] A.L. Collins, S.G. Anthony, J. Hawley and T. Turner, "The potential impact of projected change in farming by 2015 on the importance of the agricultural sector as a sediment source in England and Wales," CATENA, vol. 79 (3), pp. 243-250, Dec. 2009.

[9] R.J. Rickson, "Can control of soil erosion mitigate water pollution by sediments?" Science of The Total Environment, vol. 468–469, pp. 1187-1197, Jan. 2014.

[10] 10. A. Gobin, G. Govers, R. Jones, M. Kirkby and C. Kosmas, "Assessment and Reporting on Soil Erosion," Background and Workshop Report, Technical Report No. 94. European Environment Agency, Copenhagen, 103 pp., 2003.

[11] R.J.A. Jones, Y. Le Bissonais, P. Bazzofi, J. Sanchez Diaz, O.Duwel, G. Loj, L. Oygarden, V. Prasuhn, B. Rydell, P. Strauss, J. Berenyi Uveges, L. Vandekerckhove, Y.Yordanov, "Technical Working Group on Erosion. Task Group 2 on Nature and Extent of Soil Erosion in Europe," Final Report, European Commission, Directorate-General Environment, Brussels, May 2004.

[12] J. Soms, A. Grišanovs, "Application of ArcGIS for generation of DEM and modelling of erosion processes: problems, limitations and solutions, (ArcGIS programmproduktu pielietojums DRM ģenerēšanai un erozijas procesu modelēšanai: problēmas, ierobežojumi un risinājumi)," In: book of abstracts of the 68th scientific conference of University of Latvia, (February 2, 2010), pp. 218.-220. (in Latvian)

[13] J.Soms, "Application of GIS modelling for the assessment of environmental off-site impacts of soil erosion and sediment transport from headwater catchments to the river Daugava," In: Book of abstracts of 8th International scientific conference „The Vital Nature Sign". Kaunas, Vytautas Magnus University, Lithuania, (May 15 – 17, 2014), p.23.

[14] P. Panagos, K. Meusburger, C. Ballabio, P. Borrelli and C. Alewell, "Soil erodibility in Europe: A high-resolution dataset based on LUCAS", Science of The Total Environment, vol. 479–480, pp. 189-200, May 2014.

[15] M.A. Fullen, "Soil erosion and conservation in northern Europe," Progress in Physical Geography

[16] 16. W.S. Merritt, R.A. Letcher, A.J. Jakeman, "A review of erosion and sediment transport models," Environmental Modelling & Software, vol. 18 (8–9), pp. 761–799. Oct.-Nov. 2003., vol. 27 (3), pp. 331–358, Sept. 2003.

[17] J. de Vente, J. Poesen, G. Verstraeten, G. Govers, M. Vanmaercke, A.Van Rompaey, M. Arabkhedri, C. Boix-Fayos, "Predicting soil erosion and sediment yield at regional scales: Where do we stand?" Earth-Science Reviews, vol. 127, pp. 16-29, Dec. 2013.

[18] C. King, N. Baghdadi, V. Lecomte, O. Cerdan, "The application of remote-sensing data to monitoring and modelling of soil erosion," CATENA, vol. 62 (2–3), pp. 79-93 Aug. 2005.

[19] A. Vrieling, "Satellite remote sensing for water erosion assessment: A review," CATENA, vol. 65 (1), pp. 2-18. Jan. 2006.

[20] PSIAC (Pacific Southwest Inter-Agency Committee), "Report of the Water Management Subcommittee on Factors Affecting Sediment Yield in the Pacific Southwest Area and Selection and Evaluation of Measures for Reduction of Erosion and Sediment Yield," Report of the Water Management Subcommittee, ASCE 98, Report N. HY12, USA. 13 pp. 1968.

[21] O. Terranova, L. Antronico, R. Coscarelli, P. Iaquinta, "Soil erosion risk scenarios in the Mediterranean environment using RUSLE and GIS: An application model for Calabria (southern Italy)," Geomorphology, vol. 112 (3–4), pp. 228-245, Nov. 2009.

[22] W.H. Wischmeier, D.D. Smith, "Predicting rainfall erosion losses: a Guide for Conservation Planning," Agricultural Research Service Handbook No 537, United States Department of Agriculture, Agricultural Research Service, Washington, DC. 56 pp. 1978.

[23] K.G. Renard, G.R. Foster, G.A. Weesies, J.P. Porter, "RUSLE, revised universal soil loss equation," Journal of Soil and Water Conservation, vol. 46 (1), pp. 30– 33. Febr. 1991.

[24] D.B. Beasley, L.F. Huggins and E.J. Monke, "ANSWERS: a model for watershed planning," Transactions of the American Society of Agricultural Engineers, vol. 23 (4), pp. 938–944, Aug. 1980.

[25] M.A. Nearing, G.R. Foster, L.J. Lane, S.C. Finckner, "A process-based soil erosion model for USDA-Water erosion prediction project technology," Transactions of the American Society of Agricultural Engineers, vol. 32 (5), pp.1587– 1593. Nov. 1989.

[26] R.P.C. Morgan, J.N. Quinton, R.E. Smith, G. Govers, J. Poesen, K. Auerswald, G. Chisci, D. Torri, M.E.Styczen, "The European Soil Erosion Model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments," Earth Surface Processes and Landforms, vol. 23 (60), pp. 527– 544. Dec. 1998.

[27] Kirkby M.J., Jones R.J.A., Irvine B., Gobin A, Govers G., Cerdan O., Van Rompaey A.J.J., Le Bissonnais Y., Daroussin J., King D., Montanarella L., Grimm M., Vieillefont V., Puigdefabregas J., Boer M., Kosmas C., Yassoglou N., Tsara M., Mantel S., Van Lynden G.J. and Huting J., 2004. Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73). European Soil Bureau Research Report No.16, EUR 21176, 18 pp. and 1 map in ISO B1 format. Office for Official Publications of the European Communities, Luxembourg.

[28] H.S. Wheater, A.J. Jakeman, K.J. Beven, "Progress and directions in rainfall-runoff modelling" in Modelling Change in Environmental Systems, Eds. A.J. Jakeman, M.B. Beck, M.J. McAleer, Chichester: John Wiley and Sons, 1993, pp. 101–132.

[29] C. S. Renschler, J. Harbor, "Soil erosion assessment tools from point to regional scales – the role of geomorphologists in land management research and implementation," Geomorphology, vol. 47 (2–4), pp. 189-209, Oct. 2002.

[30] H. Zhang, Q. Yang, R. Li, Q. Liu, D. Moore, P. He, C. J. Ritsema, V. Geissen, "Extension of a GIS procedure for calculating the RUSLE equation LS factor," Computers & Geosciences, vol. 52, pp. 177-188, Mar. 2013.

[31] P. Panagos, K. Meusburger, M. Van Liedekerke, C. Alewell, R. Hiederer and L. Montanarella, "Assessing soil erosion in Europe based on data collected through a European network," Soil Science and Plant Nutrition, Special Issue: Soil and land degradation, vol. 60 (1), pp. 15 – 29. Jan. 2014.

[32] A. Sileika, "An adaptation of the agricultural nonpoint source pollution model to Lithuania," Baltic basin agriculture and environment series report, 96-BB2, 1-35. 1996.

[33] A. Skrupskis, "Development of large-scale geological map of the nature park "Daugavas loki" (Dabas parka „Daugavas loki" lielmēroga ģeoloģiskās kartes sagatavošana)", B.S. thesis, Daugavpils, Daugavpils University, 71 pp. (in Latvian), 2013.

[34] D.K. McCool, G.R.Foster, C.K. Mutchler, L.D.Meyer, "Revised slope length factor for the universal soil loss equation," Transactions of the American Society of Agricultural Engineers, vol. 32 (5), pp. 1571–1576. Oct. 1989.

[35] A. Grišanovs, "Estimation of soil erosion risk in the nature park "Daugavas loki" (Augsnes erozijas riska novērtējums dabas parkā „Daugavas loki" teritorijā)", B.S. thesis, Daugavpils, Daugavpils University, 68 pp. (in Latvian), 2009.

[36] Methods in Stream Ecology. Edit. F.Richard Hauer, Gary A. Lamberti. Academic Press, London, 1996, p.123-134.

[37] W.E. Dietrich, C.J. Wilson, D.R. Montgomery, J. McKean and R. Bauer, "Erosion thresholds and land surface morphology," Geology, vol. 20 (8), pp. 675–679, Aug. 1992.

[38] G.O. Schwab, D.D. Fangmeier, W. J.Elliot, R.K. Frevert, Soil and Water Conservation Engineering. 4th edit. John Wiley & Sons, New York, 507 pp. 1993.

[39] F.G.A. Verheijen, R.J.A. Jones, R.J. Rickson and C.J. Smith, "Tolerable versus actual soil erosion rates in Europe," Earth-Science Reviews, vol. 94 (1-4), pp. 23-38. May 2009.

[40] P.I.A. Kinnel, "Why the Universal Soil Loss Equation and the revised version of it do not predict event erosion well," Hydrological Processes, vol. 19 (3), pp. 851–854, Febr. 2005.

[41] L.M. Glymph, "Evolving emphases in sediment yield predictions," Present and Prospective Technology for Predicting Sediment Yields and Sources, USDA ARS-S-40, pp. 1–4, 1975